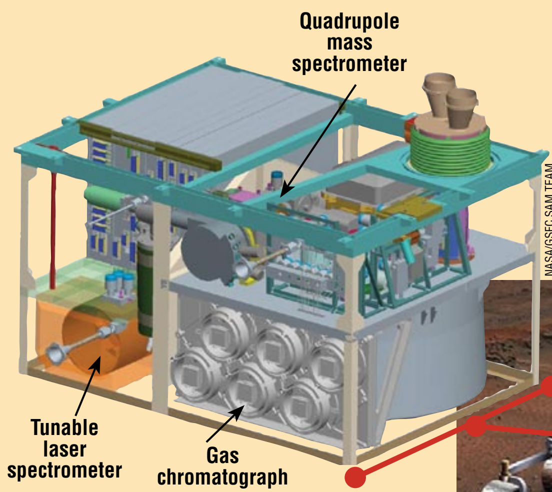
"Follow the Carbon." Follow the What?

By Lora Bleacher

"Follow the yellow brick road." "Follow the leader." You are probably familiar with both of these phrases. But who would want to "follow the carbon" and what does that even mean? To NASA, "follow the carbon" means to identify carbon-bearing compounds, their sources, and the processes that transform them in order to evaluate the habitability of Mars. And that is exactly what the Sample Analysis at Mars (SAM) suite of instruments on board the Mars Science Laboratory (MSL) intends to do.

MSL is scheduled to launch in late 2009 and will land on the surface of Mars in mid-2010, where it will spend at least one Mars year (687 Earth days) roving around the surface and collecting data. MSL will be the biggest rover yet to visit Mars. It will also carry the biggest suite of instruments ever sent to the Martian surface, including a camera, neutron detector, laser, microscope, and an analytical laboratory. SAM is one component of this laboratory.



Sample Analysis at Mars (SAM) suite of scientific instruments that will be on board the MSL rover

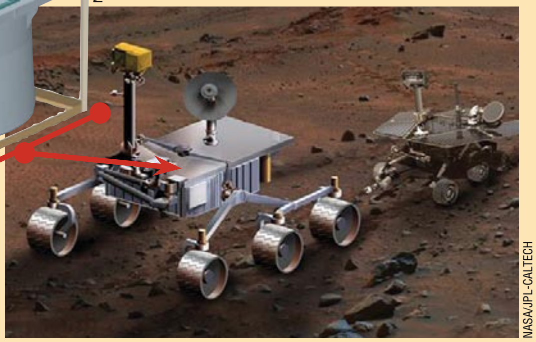


Figure 1. Illustration showing one of the two Mars Exploration Rovers (right) currently on Mars, along with the much larger Mars Science Laboratory rover (MSL) (left), which will be the largest rover ever to explore Mars.

SAM plans to "find the carbon" on Mars by collecting samples of the soil and atmosphere and analyzing them with three scientific instruments: a quadrupole mass spectrometer, a gas chromatograph, and a tunable laser spectrometer (see Fig. 1 and sidebar: **"Some Instruments Used to Study the Composition of Chemical Compounds"**). Using the results obtained by the SAM instruments, scientists back on Earth will seek to investigate the habitability of Mars by answering the question, "What do the presence or absence and characteristics of key compounds at Mars tell us about the ability of Mars to support past or present life?"

So what makes carbon so special that NASA wants to "follow it"?

In addition to liquid water and an energy source, the element carbon (C) is essential for life as we know it—that is, terrestrial life—along with other elements such as hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), phosphorus (P), calcium (Ca), and iron (Fe).

You are probably familiar with many carbon-bearing compounds, such as carbon dioxide (CO_2) and carbon monoxide (CO). When carbon is bonded to hydrogen, the resulting compound is called an organic compound.

The simplest organic compound is methane (CH_4) because it contains one carbon atom bonded to four hydrogen atoms. In addition to the carbon and hydrogen required to make a compound organic, organic compounds may also contain other elements such as oxygen, sulfur, and nitrogen. Carbon can make single, double, or triple bonds. Carbon also has the ability to bond with other carbon atoms, such that it makes long "chains" or "rings" (see Fig. 2). Because of carbon's ability to bond with many atoms in so many different ways, there are millions of organic compounds!

Every aspect of life as we know it on Earth involves organic chemistry. Your body, the food you eat, and the trees in your yard, for example, contain organic molecules. Even the smell of a rose and the hotness of a pepper are controlled by specific organic molecules.

On Earth, the simplest organic compound, methane, is primarily produced through the decomposition of biodegradable materials in wetlands and landfills and as a byproduct of digestion in humans and other animals, such as cows. The process of methane production, called methanogenesis, relies on organisms called methanogens.

Methanogens are single-celled organisms that undergo anaerobic respiration, meaning that they do not require oxygen. Although some methanogens can live in relatively mild environments, such as wetlands and the guts of humans and cows, other methanogens are extremophiles, meaning that they can survive in environments with extremely hot or cold temperatures or environments that are very saline, acidic, or alkaline.

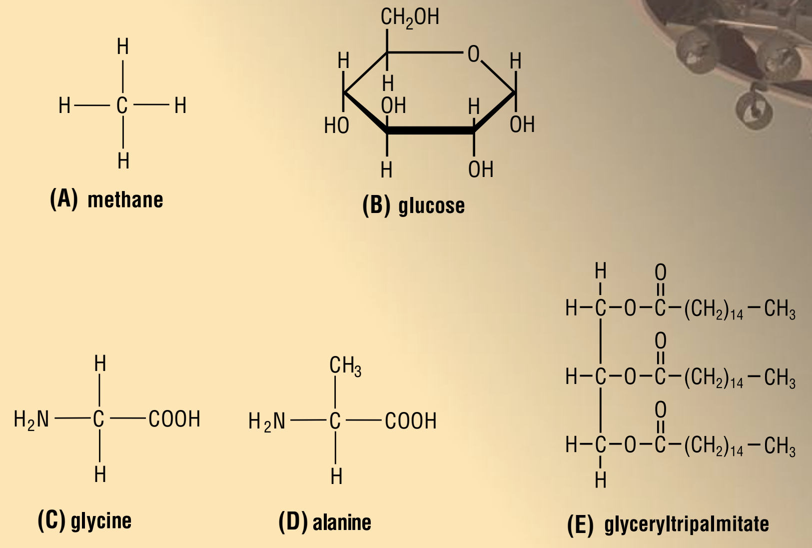


Figure 2. Examples of organic molecules: methane (A), glucose (B), glycine (C), alanine (D), and glyceryltripalmitate (E).

Two chemical reactions involved in methanogenesis are:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$
$$4CO + 2H_2O \rightarrow CH_4 + 3CO_2$$

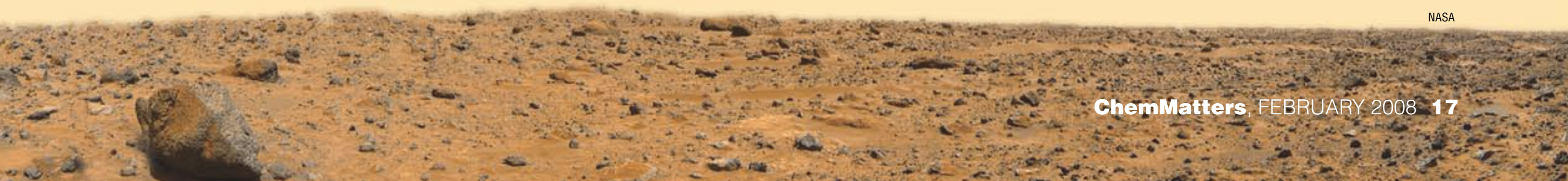
What have we found on Mars so far?

NASA has already sent landers, such as the Viking missions in 1975 and Pathfinder in 1996, and rovers, such as Sojourner in 1996 and the Mars Exploration Rovers in 2004 (which are still in operation as of the writing of this article) to Mars.

Did we detect any methane or other organic compounds on the surface of Mars with these missions? The Viking landers, which were sent to Mars specifically to look for chemical evidence of past or present life on its surface, heated soil and crushed rock samples and then used a gas chromatograph mass spectrometer (GCMS) to measure the mass of any molecules present (see Fig. 3 and sidebar **"Some Instruments Used to Study the Composition of Chemical Compounds"** for more information about a GCMS).

No methane or other organic compounds were detected. But some scientists think that the temperature to which the samples were heated in the Viking experiments (500 °C) was simply not hot enough to have revealed any

Prototype of the MSL from a test conducted in June 2007 in the "Mars Yard" of the Jet Propulsion Laboratory. The rocks are intended to simulate the shape and size of rocks on Mars that MSL might encounter.



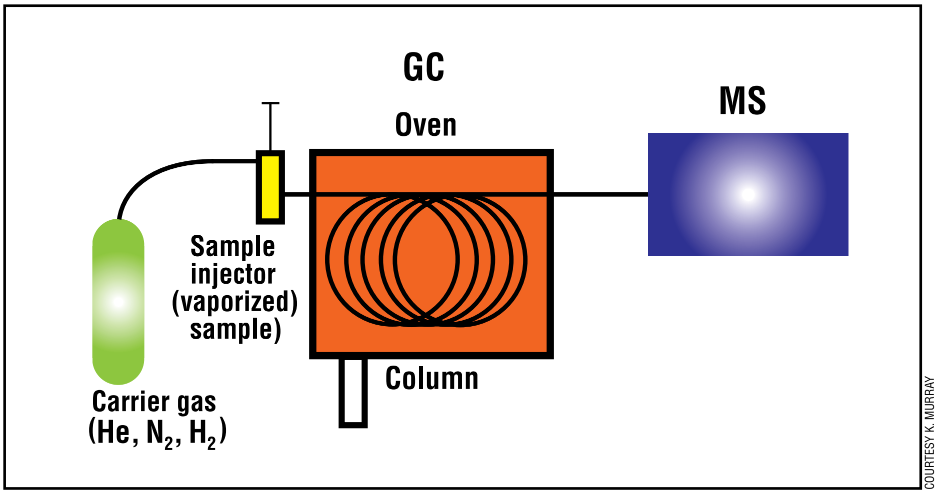


Figure 3. A gas chromatograph mass spectrometer consists of two parts: a gas chromatograph (GC), which is made of a sample injector (yellow) and a column oven (red) and a mass spectrometer (MS). After a soil or rock sample is heated to a temperature hot enough to vaporize it, the resulting gas (yellow) travels through a column within the GC. It takes longer for some molecules to travel through the column than others, so they enter the MS at different times. In the MS, the molecules are identified based on their mass.

organic compounds that may have been present, especially if they were refractory (that is, resistant to heating).

Another possibility is that organic compounds may have gone undetected because they were oxidized into carbon dioxide before being identified with the GCMS. In addition, some scientists think that organic compounds such as those that may be present on Mars may not respond to heating at all. They propose that other chemical techniques should be used when looking for organic compounds on the Martian surface.

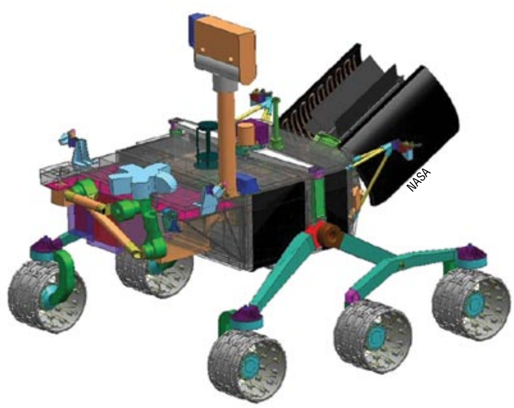
The SAM suite of instruments on the MSL will employ a GCMS and will use both of these methods. It will heat samples to higher temperatures (1000 °C) than did the Viking instruments, and it will use chemical extraction in addition to heating in order to identify any organic compounds that may be present.

Although organic compounds have not been detected at the Martian surface, a small amount of methane was detected in the Martian atmosphere by the Mars Express, a European Space Agency orbiter, in 2003. The Canada-France-Hawaii Telescope and the NASA Infrared Telescope Facility have also observed methane in the Martian atmosphere, but the source of the methane is unknown.

Could living organisms on Mars have produced the methane observed in the atmosphere and additional organic compounds at the Martian surface that are yet to be detected? Maybe. Other possibilities are that the atmospheric methane was delivered to Mars by the meteorite and comet impacts that it has experienced over and over throughout its existence, that methane has been released into the atmosphere by volcanoes, or that the methane forms as a result of a chemical reaction, involving the hydration of certain minerals found in rocks on Mars.

Will the SAM instruments be able to tell the difference between these potential sources of methane should they, in fact, find evidence of methane or other organic compounds in surface materials on Mars? Scientists may be able to distinguish the source of organic compounds on Mars by looking for patterns that are similar to those in organic compounds on Earth, in terms of their molecular structure, abundance, isotopic compositions, and geochemical contexts.

Take carbon isotopes, for example. Remember that an isotope is an atom that has a different number of neutrons in its nucleus compared to another atom of the same element. Both atoms are the same element because they have the same number of protons, but they have different masses due to different numbers of neutrons. Carbon-12 has six protons and six neutrons, carbon-13 has six protons and seven neutrons, and carbon-14 has six protons and eight neutrons (see Table 1 and Fig. 4).



SAM will measure the carbon-13/carbon-12 ratio of both methane and carbon dioxide in atmospheric samples and in the soils it collects and heats (as the samples are heated, they will release carbon dioxide and methane if present) in order to distinguish between the different sources of carbon on Mars.

Orbiter, lander, rover: What's the difference?

Orbiter: Spacecraft designed to orbit a planetary body but not to land on it.

Lander: Spacecraft designed to land on the surface of a planetary body.

Rover: Small vehicle launched from a lander that is designed to explore a planetary body.

THREE CARBON ISOTOPES				
Name	**Total Protons**	**Total Neutrons**	**Total Protons & Neutrons**	**Total Electrons**
CARBON-12	6	6	12	6
CARBON-13	6	7	13	6
CARBON-14	6	8	14	6

Table 1. Differences between three carbon isotopes: carbon-12, carbon-13, and carbon-14.

Organic compounds made by organisms on Earth favor carbon-12 over carbon-13 in a process called isotopic fractionation. During this process, heavy and light isotopes partition differently between two compounds. This happens because the bond energy of each isotope is slightly different, with heavier isotopes having stronger bonds and slower reaction rates.

Because light isotopes form weaker chemical bonds in a compound than heavy isotopes, it requires less energy to form bonds between carbon-12 atoms than it does between carbon-13 atoms and carbon-12 atoms in a compound. Organic compounds on Mars may exhibit a similar fractionation trend if produced by past or present organisms.

Scientists may also be able to use a carbon isotope pattern to distinguish any organic compounds it finds as being from Mars instead of from meteorite impacts. This is because the most common type of meteorite to fall on Earth, and presumably Mars, called chondrites, has been found to contain “abiotic” organic compounds, that is, the organic compounds were not made by biological organisms. The carbon in this meteoritic material is enriched in the isotope carbon-13 relative to carbon-12.

However, some abiotic physical processes can also fractionate isotopes. Thus, the SAM scientists must take into account multiple lines of evidence—such as the environmental context from which samples are taken and analyzed—when evaluating the habitability of Mars.

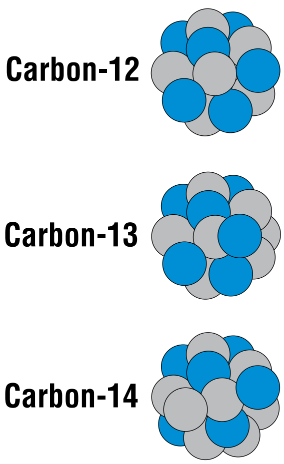


Figure 4. Nuclei of three carbon isotopes, containing (from top to bottom) six, seven, and eight neutrons (gray) and six protons each (blue).

Did life ever exist on Mars? Stay tuned …

The SAM suite of instruments will be used to explore the conditions necessary for life on Mars as it rides aboard the largest, most technologically advanced rover ever sent to the red planet! SAM will “find the carbon” on Mars using its comprehensive suite of three scientific instruments that will work together, along with other instruments on board the rover, to investigate the habitability of Mars.

Follow the engineers and scientists behind SAM and the MSL mission at **http://ael.gsfc.nasa.gov/marsIndex.shtml and http://mars.jpl.nasa.gov/msl/**.

REFERENCES

Mars Science Laboratory: **http://mars.jpl.nasa.gov/msl/**

Mars Science Laboratory’s instruments: **http://mars.jpl.nasa.gov/msl/mission/sc_instruments.html**

Past, present, and future missions to Mars: **http://mars.jpl.nasa.gov/missions/index.html**

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Some Instruments Used To Study the Composition of Chemical Compounds

Spectrometer: Measures the interaction between light and a material and analyzes the light absorbed, emitted, or scattered by this material to determine its chemical composition.

Mass spectrometer: Breaks a sample apart by vaporizing and ionizing its constituents, and then separates these ions according to their mass and charge, which helps determine the chemical composition of the sample.

Laser spectrometer: Determines the chemical composition of a material by measuring how this material interacts with light from a laser.

Quadrupole mass spectrometer: Uses oscillating electrical fields to separate the ions according to their mass and charge.

Gas chromatograph: Separates the components of a sample by vaporizing it into a stream of gas and passing the gas through a column whose walls are covered with a polymer; the different components of the sample stick differently to the polymer, which helps separate them and later identify them based on their respective affinities for the polymer.

Gas chromatograph-mass spectrometer: A combination of a gas chromatograph and a mass spectrometer: separates the components of a sample by vaporizing it into a stream of gas and passing the gas through a column, and then analyzes these components with a mass spectrometer.

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